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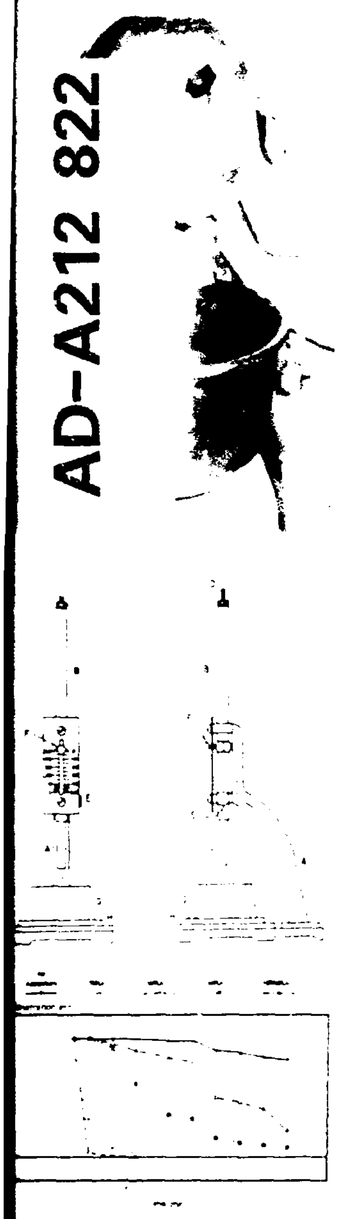

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INVESTIGATION OF EARLY STIFFENING OF CONCRETE AT RED RIVER LOCK AND DAM NO. 3

by

Toy S. Poole, John B. Cook

Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road
Vicksburg, Mississippi 39180-6199

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Slump loss was experienced in a concrete used in construction of Red River Lock and Dam 3. A three-factor laboratory analysis was conducted to determine whether properties of the cement, the fly ash, or the mixing water, or some combination of these properties were responsible for this behavior. Pesults (ASTM C 359) indicated that the cement in combination with the project water was the primary cause of early stiffening behavior. The stiffening was due to false-set. Increasing fly ash replacements and changing the mixing procedure tended to reduce the magnitude of the problem. This problem was solved by modifications in the manufacturing procedure of the cement so that formation of plaster of Paris was avoided. Following this modification, an apparent cement-admixture interaction was suspected as another cause of early stiffening. Some water-reducing admixtures (WRA's) were found to be associated with early stiffening. Recommendations were to use one of the WRA's that did not cause early stiffening or to avoid WRA's altogether.

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Preface

The investigation described in this paper was conducted for the US Army Engineer District, Vicksburg, as part of the quality assurance support during construction of Red River Lock and Dam No. 3. Funding was under Contract No. DACW38-88-C-0046.

The work was performed at the US Army Engineer Waterways Experiment Station (WES) by the Cement and Pozzolan Unit, Concrete Technology Division (CTD), Structures Laboratory (SL).

The investigation was completed under the general supervision of Messrs. Bryant Mather, Chief, SL; Kenneth L. Saucier, Chief, CTD; and Richard L. Stowe, Chief, Materials and Concrete Analysis Group, CTD. Mr. Toy S. Poole, CTD, directed the investigation and wrote the report, with Mr. John B. Cook, CTD, executing the work.

Acting Commander and Director of WES during the preparation of this report was LTC Jack R. Stephens, EN. Technical Director was Dr. Robert W. Whalin.

Contents

Conversion Factors, Non-SI To SI (Metric) Units Of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
inches	25.4	millimetres
ounces (volume)	0.02957353	litres
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals

INVESTIGATION OF EARLY STIFFENING OF CONCRETE AT RED RIVER LOCK AND DAM NO. 3

Introduction

The purpose of the work was to investigate a loss in slump of concrete at the Red River Lock and Dam No. 3 construction site. The mixture in question, which had a slump of 2 1/2 in. during mixture proportioning, experienced a 1-in. slump loss in about 30 min when used at the construction site. There was concern that this loss in workability would develop into a handling and placing problem.

The work was executed in two stages. In the first part, the cement, water, and fly ash were examined to determine whether properties of any one or combination was the cause of early stiffening. As a result of this effort, a modification of the cement was made by the manufacturer, but the problem continued. In the second part of the work, cement-admixture interaction was examined.

Materials and Methods

American Society for Testing and Materials (ASTM) method C 359-83 (ASTM 1988b) was used as a laboratory tool for measuring early stiffening. In this method, penetration of a 10-mm diameter plunger (Vicat apparatus) into a mass of mortar is measured at the end of the mixing cycle, again at 5 min, at 8 min, at 11 min, and after 1-min of remixing. This test sequence was modified such that penetration readings were taken at 3, 8, 15, 21, 27, and 30 min, followed by a remixing cycle and a final penetration reading. The method was also modified by replacing 33% of the portland cement (by volume) with fly ash, as called for in the concrete mixture.

Depth of penetration was found to decrease with time in an approximately linear manner; therefore, the slope of the penetration versus time linear regression equation was used as a measure of loss of workability for purposes of statistical analysis of differences among components. This measure is expressed in units of mm/min. However, for

purposes of illustrating stiffening behavior, penetration versus time curves will mostly be used.

Concrete mixture B-1-1 was in use when the slump-loss problem was identified. This mixture contains 291.1 lb/yd^3 of portland cement and 122.9 lb/yd^3 of fly ash. This represents a 34% replacement by solid volume. The water cement ratio is 0.52 by mass. The complete mixture proportions are given in Table 1.

Part 1

Two cements, two fly ashes, and water from two sources were used in the first part of the study. The cements included the project cement (Type II, with the optional limits on alkali content and heat of hydration invoked, ASTM C 150 (1988a)) and another Type II from a different manufacturer. The project cement was representative of the first lot of cement manufactured to comply with the optional 7-day heat of hydration of Table 4, ASTM C 150) produced for this project. The fly ashes included the project fly ash (Class C, ASTM C 618 (1988d)) and a Class F fly ash from another source. The waters included the project water and laboratory-prepared deionized water. Properties of these materials are summarized in Tables 2 and 3. Properties presented in Table 2 representing project materials should be taken as typical since they were taken from test reports on these materials that were sampled close to the same time that materials for the ASTM C 359 (ASTM 1988b) tests were sampled, but they are not identical. X-ray diffraction analysis was conducted on the actual materials used in these tests.

All combinations of each of the cements, fly ashes, and waters were tested, in duplicate, by the modified ASTM C 359 (ASTM 1988b) procedure described above. Data were analysed in a three-way analysis of variance, completely randomized design (Steele and Torrie, 1960, or other standard statistical text), using the Statistical Analysis System (SAS) software.

Three additional investigations were conducted. These were more limited in levels of replication than was the investigation described above. (1) A comparison was made of the penetration loss for mortars containing no fly ash using the project water and deionized water. (2) The effect of various fly ash replacement levels on rate of loss of penetration was investigated. Replacement levels of 0, 25, 33, 35, and 40% by solid

volume were examined. (3) The effect of variations in C 359 mixing procedures on loss of penetration was investigated.

Part 2

In the Part 2 of the study, two samples of cement were used that represented the second lot of cement produced meeting the optional heat-of-hydration requirement for the construction project. These are represented as LMK 14-89, and LMK 29-89. The grinding aid was omitted during production of this lot of cement in an effort to reduce the amount of calcium sulfate hemihydrate in the finished product.

Four water-reducing admixtures (WRA's) were examined for effect on relative to the mortar without admixtures. Three of these were lignosulfonate-based admixtures, one of which was in use at the construction project (WRA-1). These were used at a dosage rate of 2.34 mL per 600 g of cement for ASTM C 359 (ASTM 1988b) tests (equivalent to 6 oz per cwt of cement). The fourth admixture was a high-range water reducer (HRWRA-1). It was used at a doseage rate of 1.56 mL per 600 g of cement for C 359 tests (equivalent to 4 oz per cwt of cement).

Project water was used in all ASTM C 359 tests. Fly ash was not used in any Part 2 tests.

Results

Part 1

A complete summary of data is found in Appendix A. The results of the analysis of variance are summarized in Appendix B. Components that emerged as significant at the 0.05% level were water and cement, with the former having the strongest effect. Cement-water and fly ash-water interaction effects emerged as significant. These main and interaction effects are illustrated in Figures 1 and 2. For purposes of understanding the meaning of these effects, plots of penetration versus time for various combinations of materials are probably more useful than these plots. Descriptions of these follow.

Figure 3a illustrates the effect of replacing the project water with deionized water, leaving other components of the project mixture constant, i.e., fly ash present. The deionized-water mortar loses very little

penetration relative to the project-water mortar during the 30-min test period.

Comparison of mortars made with project and with deionized water confirmed the water effect. This is illustrated in Figure 4. The mortar made with deionized water allowed a penetration of about 3 times the mortar made with project water at 11 min after mixing, although both of these mortars lost penetrability much more rapidly than mortars containing fly ash.

Figure 5 illustrates the effect of replacing the project cement with the alternate cement source, leaving other components of the project mixture constant. There is an improvement in the early stiffening behavior of the mortar with the alternate cement, but this improvement is not as pronounced as in the case of substitution of the project water with deionized water.

The interpretation of the cement-water interaction effect is that changing the water had a greater effect on stiffening caused by the project cement than on the behavior of the alternate cement. This is illustrated by comparing Figure 3a with 3b.

The interpretation of the fly ash-water interaction is that changing the water had a greater effect on stiffening of mortars containing the project fly ash than on mortars containing the alternate fly ash. This is illustrated by comparing Figure 6a with 6b. Even though statistically significant, this fly ash effect was not a strong one, perceptible only as an enhanced stiffening in the project-fly ash mixtures between 27 and 30 min.

The result of the analysis of different fly ash replacement levels indicated a general trend toward reduced early-stiffening problems with increasing fly ash replacements, although the effect of small changes in fly ash replacement levels was not very great as illustrated by the relatively low slope of the loss-of-penetration versus time curve (Figure 7).

The timing of the mixing cycle appeared to have a significant effect on loss of workability. Figure 8 illustrates the penetration-loss pattern for a mortar mixed according to the standard C 359 mixing cycle and the same mortar mixed for an additional 45 sec. There was no intervening rest period between the standard mixing cycle and the 45 sec additional mixing. Another mixing-cycle variation that had an effect on subsequent stiffening was to extend the blending period of dry materials in the mixing bowl from 10 sec

at low speed, as specified in C 359 (ASTM 1988b), to 30 sec or 1 min. This effect is illustrated in Figure 9.

Essentially without exception, all losses in penetration were recovered when the mortars were remixed after completion of penetration tests. This indicates that the source of the problem probably involves a calcium sulfate-related setting phenomenon rather than an accelerated hydration of the portland cement.

Examination of the cement and fly ash by X-ray diffraction indicated the presence of $CaSO_4.1/2H_2O$ (plaster of Paris) in the cement and $CaSO_4$ (anhydrite) in the fly ash.

Part 2

The second lot of cement produced for the construction project (LMK 14-89) showed considerably less tendency to stiffen with project water relative to the first lot of cement, as illustrated in Figure 10. X-ray analysis indicated no perceptible plaster of Paris in the second lot of cement.

Results from ASTM C 359 (ASTM 1988b) tests, however, indicated that this cement showed considerable variation in early stiffening with changes in admixture. Some stiffening was evident with all of the water reducing-admixtures examined, but there was substantial variation in the degree of loss in penetration. The admixture currently in use at the project (WRA-1) was among the most active in causing loss in penetration. The one high-range water reducer caused much less stiffening than the three conventional water reducers examined. These results are illustrated in Figure 11. Complete data are summarized in Appendix A.

On remixing, all of the mortars that had exhibited stiffening recovered their original penetration by the Vicat needle. However, the mortar still appeared to be substantially stiffer after remixing than at the end of the first mixing cycle.

Discussion

There are at least two different cement-related phenomena that can cause early stiffening problems in concrete. These are commonly referred to as false set and flash set (or quick set).

False set is characterized by a stiffening in the first few minutes after addition of mixing water accompanied by very little heat evolution.

The most notable characteristic is that the stiffening disappears if mixing continues for a short period (one to a few minutes). Because of this latter property, false set rarely causes a practical problem when concrete is mixed for more than about 5 min, as is commonly the case in ready-mixed concrete operations. It is usually a problem on projects when concrete is batched and mixed on site and placed within a very few minutes. The phenomenon is typically caused by the setting of plaster of Paris in the portland cement. The presence of plaster of Paris usually results from an inadvertent partial dehydration of the gypsum that is added to portland cement to control setting time. The phenomenon is also sometimes caused by abnormal hydration rates of the C_3A in the portland cement (Kalousek 1969).

Flash set is also characterized by an early stiffening, but usually a significant amount of heat is evolved and the phenomenon does not disappear with additional mixing. This phenomenon is a result of an acceleration of cement hydration. This can happen for a number of reasons (Lea 1970), among which are an insufficient gypsum content to retard set, or a cement-admixture interaction. Flash set occurs less commonly than false set but is more problematic when it does because it cannot be removed by a simple adjustment of mixing or handling procedures.

The presence of plaster of Paris in the cement and the recovery of slump by remixing clearly indicate the early-stiffening problem at Red River Lock and Dam 3, addressed in Part 1 of this study, to be a false-set problem that was exacerbated by the project water. There was no obvious property of the project water that would explain its effect on the project cement. The set of the plaster of Paris in the cement was evidently accelerated by some dissolved constituent. This water contained some insoluble material that appeared to be hydrated iron oxides (rust color, readily dissolved on acidification), but these probably were not the source of the problem since separating them out had no apparent effect on the early stiffening of the portland-cement mortar.

It is interesting to note that the standard acceptance test for false set, ASTM C 451 (ASTM 1988c), did not detect any tendency toward early stiffening. This procedure differs from ASTM C 359 (ASTM 1988b) in that penetration is measured on a paste rather than on a mortar and in that the mixing time is longer (3 min vs. 1 min). The mixing time for the concrete at the project was 1 min. As shown in these results, mixing time is

probably a critical variable affecting the expression of the early stiffening problem. Perhaps in future mixture proportioning work, early stiffening behavior should be evaluated with procedures that replicate as closely as possible the project conditions.

As mentioned above, false-set problems can typically be solved by extending mixing time by a small amount. This requires that placing schedules be adjusted, which is unacceptable to the contractor. An alternative, in this case, would be to use another water source. A third alternative would be for the cement manufacturer to modify production procedures so that less plaster of Paris is formed. The latter was accomplished by the manufacturer subsequent to the results obtained in Part 1 of this study.

The stiffening observed in Part 2 of this study also appeared to be false set, since the original penetration of the Vicat needle was recovered on remixing. This, however, is not an accurate description of the actual behavior. The 50-mm penetration recorded at the start of the test and after remixing is not an accurate reflection of viscosity because of the dimension of the test apparatus. The depth of the container holding the mortar is 50 mm, therefore, all mortars that allow $\geq$50-mm penetration appear, in the data, to have equivalent viscosities. That much workability was recovered on remixing indicates that false set was occurring, at least to some degree. That all workability was not recovered indicates that some flash set was probably also occurring.

Kalousek (1969) reported similar behavior with some portland cement-admixture combinations. He further reported that both of these phenomena can occur as a result of variations in the kinetics of formation of calcium sulfoaluminate (ettringite) from the reaction of the tricalcium aluminate (C_3A) in the portland cement and with the added gypsum, as well as by the plaster of Paris-based reaction described above. This author did not elaborate on how water-reducing admixtures sometimes cause this effect other than that they apparently affect the kinetics of ettringite formation.

Kalousek also found that exposing the cement to a few tenths of a percent water prior to batching tended to eliminate abnormal set problems. This could be accomplished by injecting a fine spray of water into the cement during transfer from storage. Since abnormal set appears to occur only with certain cement-admixture combinations, another solution is to

screen admixtures with the project cement prior to concrete mixture proportioning work.

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Lea, F. M.. 1970. The Chemistry of Cement and Concrete, 3rd ed., Chemical Publishing Company, New York.

Steele, G. D. and Torrie, J. H.. 1960. Principles and Procedures of Statistics, McGraw-Hill, New York.

Table 1. Mixture Proportion for Concrete Mixture B1-1.

JOB NAME		CONCRETE MIXTURE PROPORTIONS (WORK SHEET)	DATE 24 August 1988
JOB NO	MIXTURE SER NO B1-1		INITIALS

PORTLAND CEMENT TYPE	POZZOLAN SER NO	A. E. ADMIX SER. NO.
SER NO ADDITION	TYPE	NAME Daravair
BRAND AND MILL	SOURCE	AMOUNT 0.95 oz/cwt ML

OTHER CEMENT SER NO	CHEMICAL ADMIX SER. NO ML
BRAND AND MILL	NAME WRDA-79 6oz/cwt

FINE AGGREGATE		COARSE AGGREGATE	
TYPE	SER. NO.	TYPE	SER. NO
SOURCE		SOURCE	SIZE 1 1/2

MATERIALS

MATERIAL	SIZE RANGE	BULK SPECIFIC GRAVITY	UNIT WEIGHT (SOLID), LB CU FT	ABSORPTION, PERCENT	TOTAL MOISTURE CONTENT, PERCENT	NET MOISTURE CONTENT PERCENT
CEMENT						
Fly Ash			157.87			
F. AGGREGATE			162.82			+2.3
C. AGGREGATE (A) 51%	3/4		166.61			-0.6
C. AGGREGATE (B) 49%	1 1/2		167.86			-0.4
C. AGGREGATE (C)						
C. AGGREGATE (D)						
POZZ OTHER CEMENT						

PROPORTIONS

MATERIAL		CALCULATED BATCH DATA (1 CU YD) SOLID VOLUME CU FT BATCH	SAT. SURF DRY BATCH WT LB	FACTOR	ACTUAL BATCH DATA 2.6 CU FT SAT. SURF DRY BATCH WT LB	WATER CORRECTION, LB	ACTUAL BATCH WT
CEMENT		1.481	291.1 (13)				28.0
Fly Ash		0.493	77.9				7.5
F. AGGREGATE		7.858	1279.4	15.3 94.8	123.2	+2.8	126.0
C. AGGREGATE (A)		6.268	1044.4	-.5 77.4	100.6	-0.6	100.0
C. AGGREGATE (B)		6.023	1011.0	-.3 74.9	97.4	-0.4	97.0
C. AGGREGATE (C) FA		0.283 (11)	45.0				4.3
C. AGGREGATE (D) AEA		(10)	3.5oz				10ml
POZZ OTHER CEMENT WRA			22.1oz				63ml
WATER		3.109	193.0 (3)	-4.5 14.3	18.6	-1.8	16.8
AIR		1.485					
TOTAL	AIR FREE	25.515 (5)	3942.8 (4)				
	YIELD	27.000 (14)					

MIXTURE DATA

SLUMP 2 1/2 IN	AIR CONTENT (D) 6.6 %	MIXING WATER F	TH CF LB/CU YD
REMOLD EFF DROPS	AIR CONTENT (E) %	AMBIENT F	ACT CF LB/CU YD
TH UW 154.5 LB CU FT	AIR CONTENT (F) 6.0 %	CONCRETE F	W/C 0.50 WT
ACT UW 144.4 LB CU FT	BLEEDING %	S/A 39 PERCENT VOL	

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Table 2. Typical Properties of Cements and Pozzolans.

PORTLAND CEMENT

Property	Project Cement LMK-136-88	Alternate Cement SWF-145-88
SiO_2	22.1	20.8
Al_2O_3	4.9	4.9
Fe_2O_3	5.2	3.9
CaO	62.3	64.7
MgO	0.8	0.9
SO_3	2.0	2.7
Na_2O	0.11	0.27
K_2O	0.54	0.39
LOI	1.3	0.7
Insoluble Residue	0.44	0.21
TiO_2	0.18	0.24
P_2O_5	0.19	0.22
C_3A	5	8
C_3S	37	56
C_2S	36	17
C_4AF	16	12
Initial Set, min	180	110
Final Set, min	305	250
False Set, %	112	-
3-Day strength, psi	1700	2970
7-Day strength, psi	2480	4240
Autoclave expansion, %	0.00	0.01
Blaine fineness, m^2/kg	330	366
Air Content, %	7	9

FLY ASH

	Project Fly Ash LMK-135C-88	Alternate Fly Ash WES-14F-88
SiO_2	30.8	51.2
Al_2O_3	14.8	29.0
Fe_2O_3	8.6	7.4
CaO (typical analysis)	20	2
MgO	5.4	0.9
SO_3	3.0	0.5
LOI	0.2	3.6
Retained 45-micrometre (No. 325) sieve, %	13	20
Water Requirement, %	92	98
Density	2.70	2.31
Autoclave expansion, %	0.00	0.01
Pozzolanic Activity w/ Lime, psi	-	1310
Pozzolanic Activity w/ Cement, %	94	108

Table 3. Analysis of Project Water (LMK-8 W-1).

Constituent	Content, ppm
total solids	915
Na	86
K	3.3
Fe*	7.5
SO_4	37.4
Cl	164
Alkalinity	454

* Water contained some undissolved solids when received. These appeared to be hydrated iron oxide. These were dissolved by acidification and included in the chemical analysis.

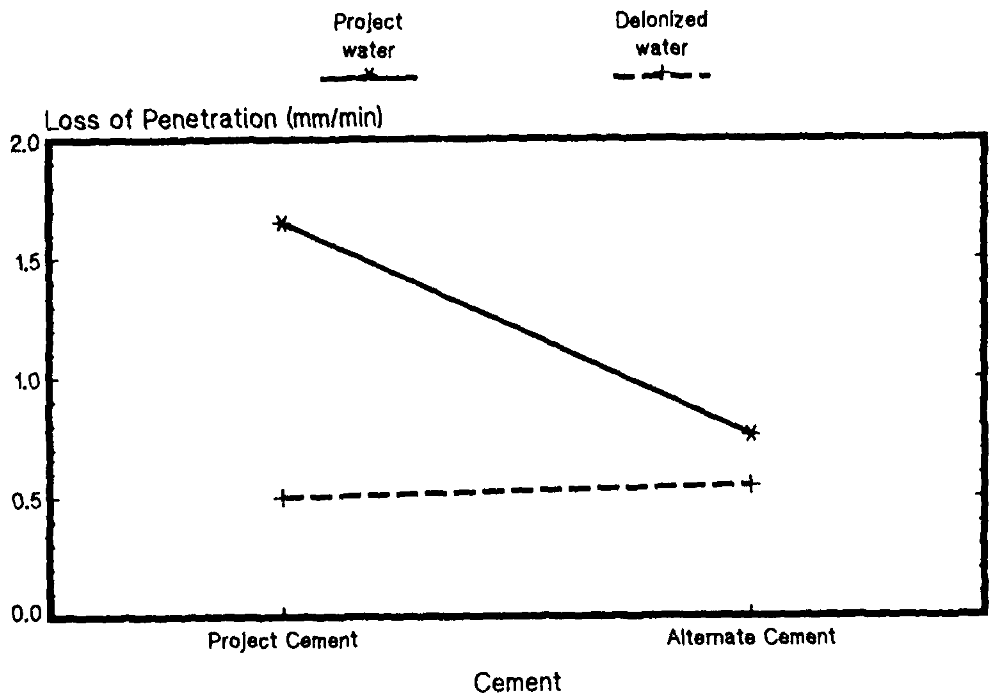


Figure 1. Illustration of analysis of variance main effects, water and *cement*, on rate of loss of penetration in ASTM C 359 tests.

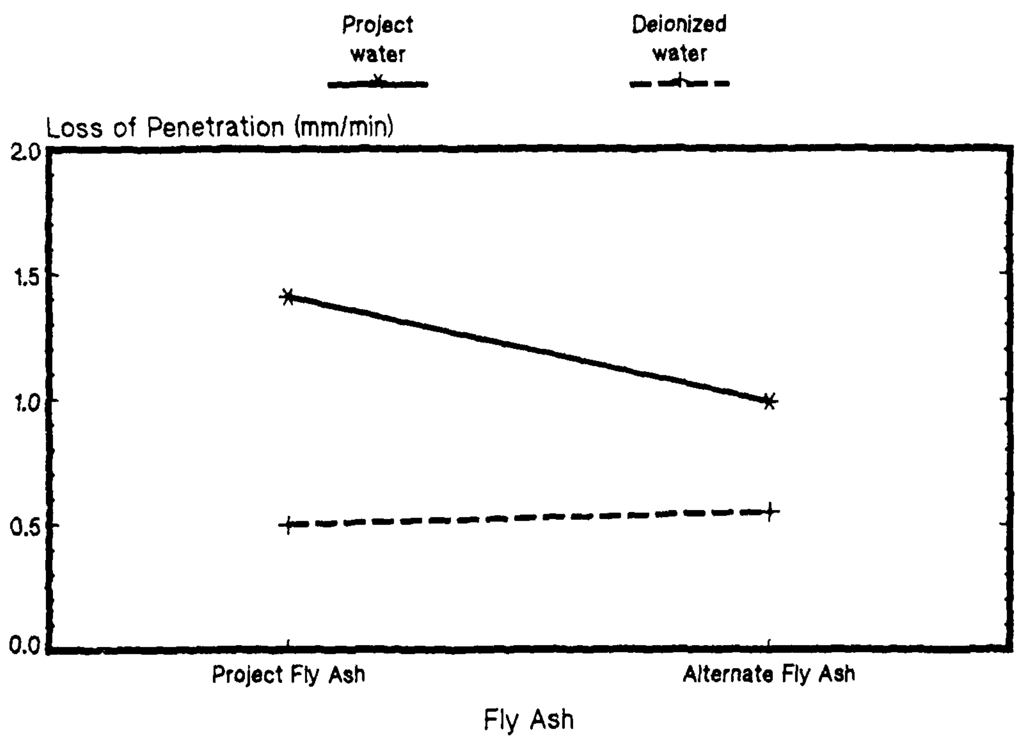
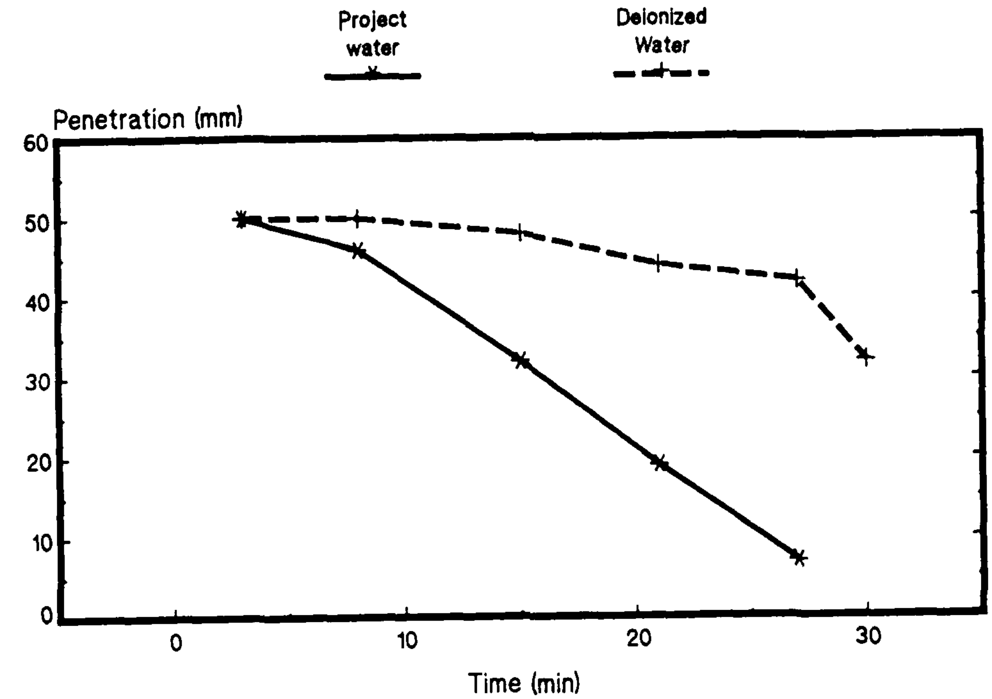


Figure 2. Illustration of analysis of variance main effects, fly ash and water, on rate of loss of penetration in ASTM C 359 tests.



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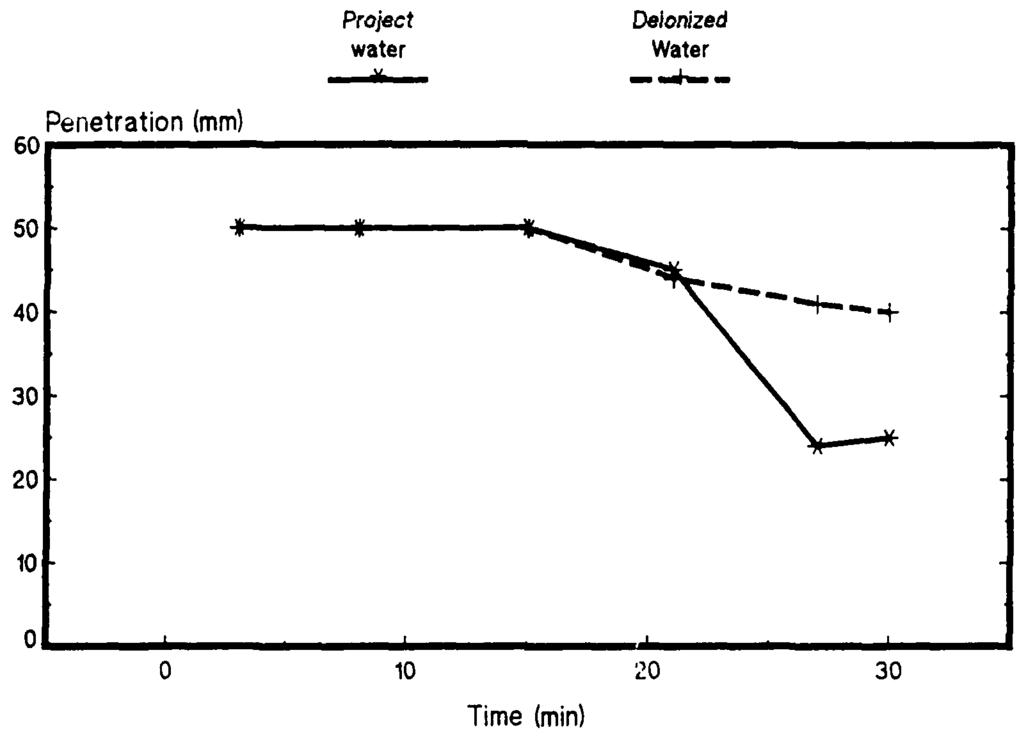


3b.

Figure 3. Effect of changing water on penetration vs. time curves: a. using project cement; b. using an alternate cement. Each curve represents the mean of 2 tests.

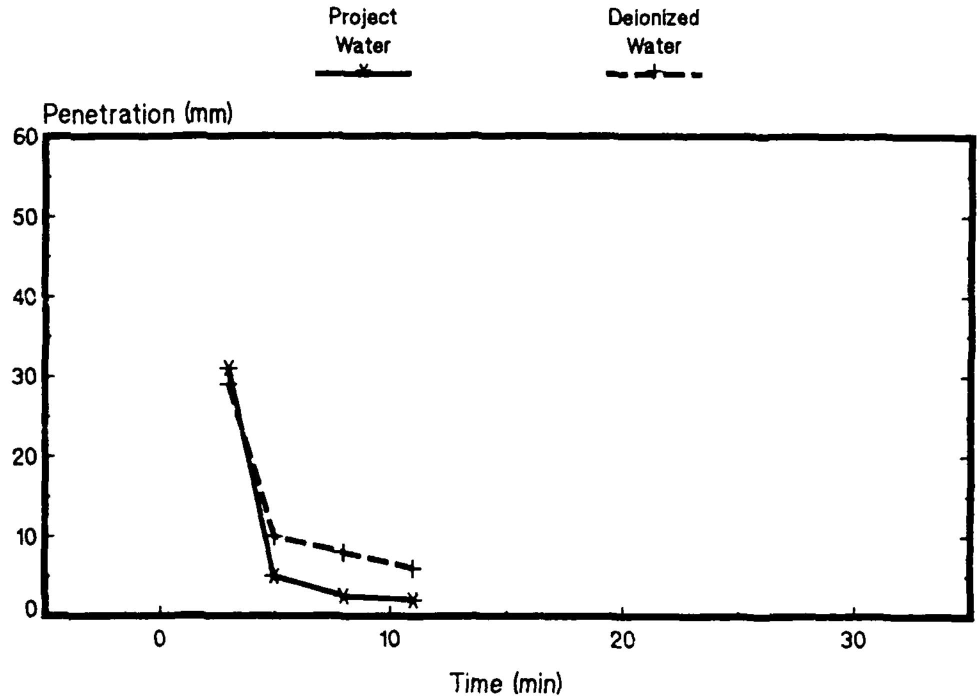


Figure 4. Effect of changing water source on penetration vs. time behavior of neat cement mortars, using project cement. Each curve represents a single test.

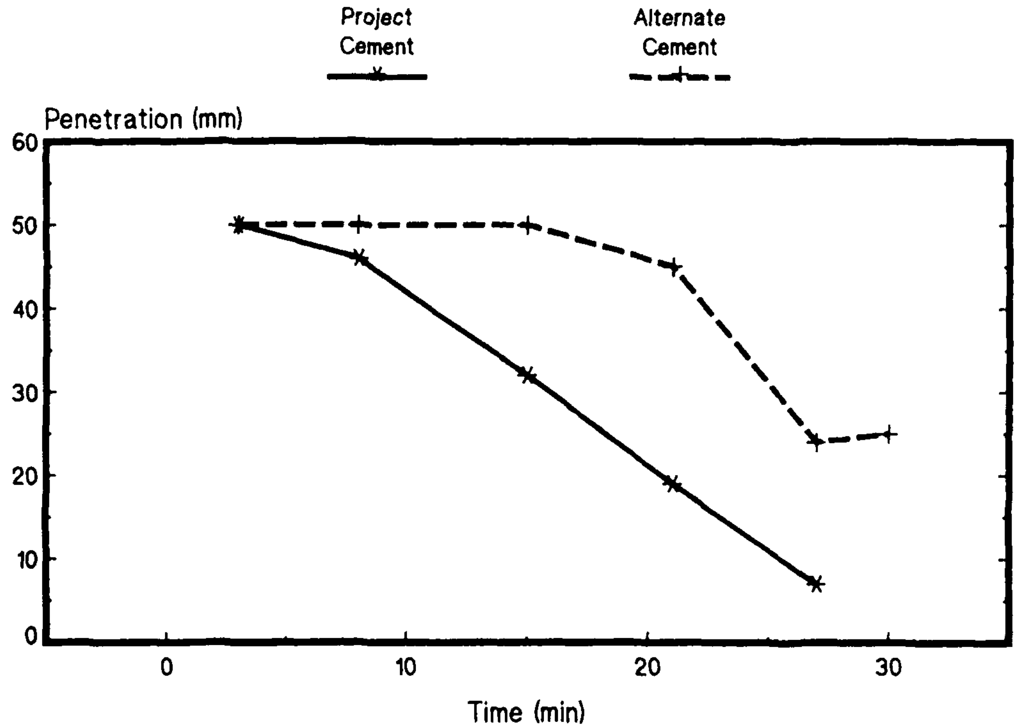
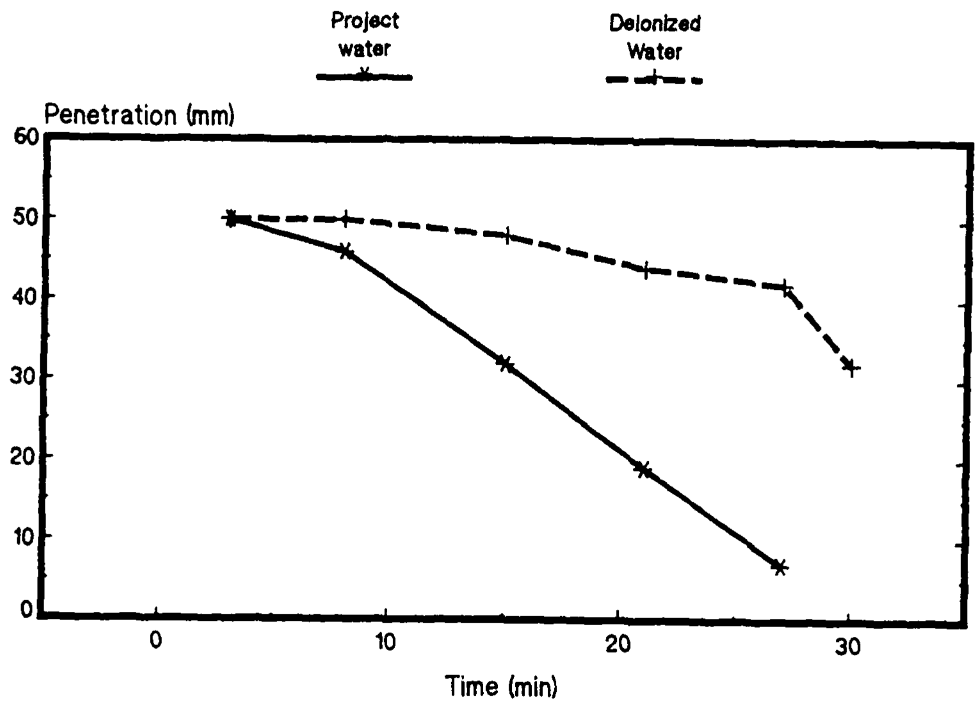


Figure 5. Effect of changing cement on penetration vs. time behavior. Each curve represents the mean of 2 tests.



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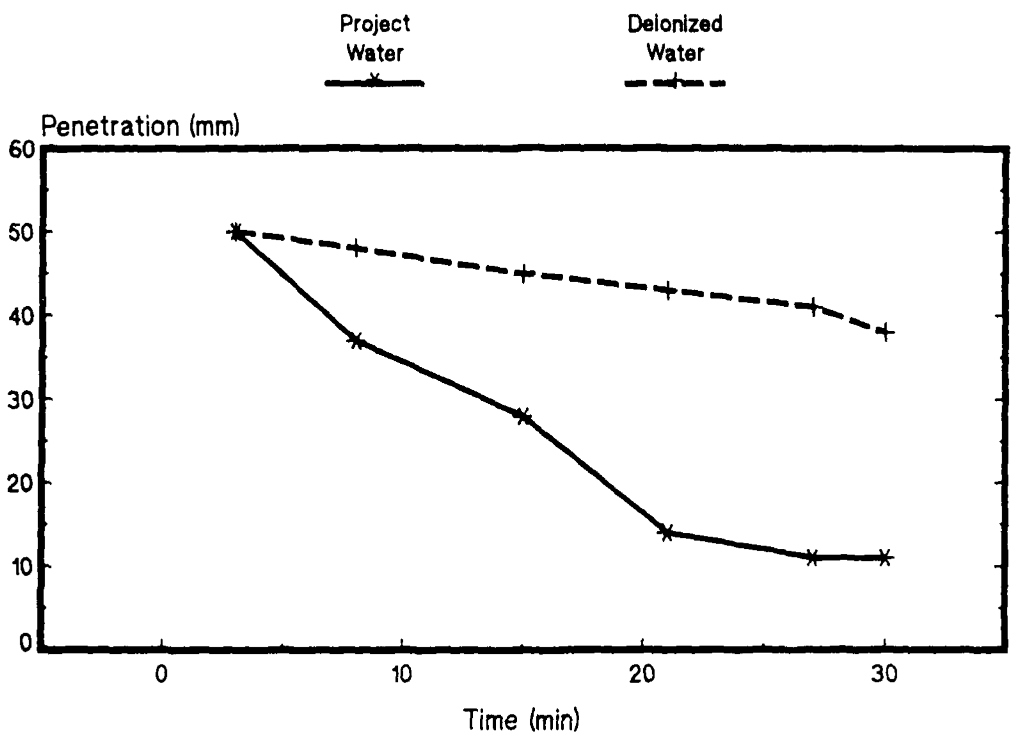

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Figure 6. Comparison of the effect of changing fly ash on penetration vs. time behavior of mortars: a. project fly ash; b. alternate fly ash source. Each curve represents the mean of 2 tests.

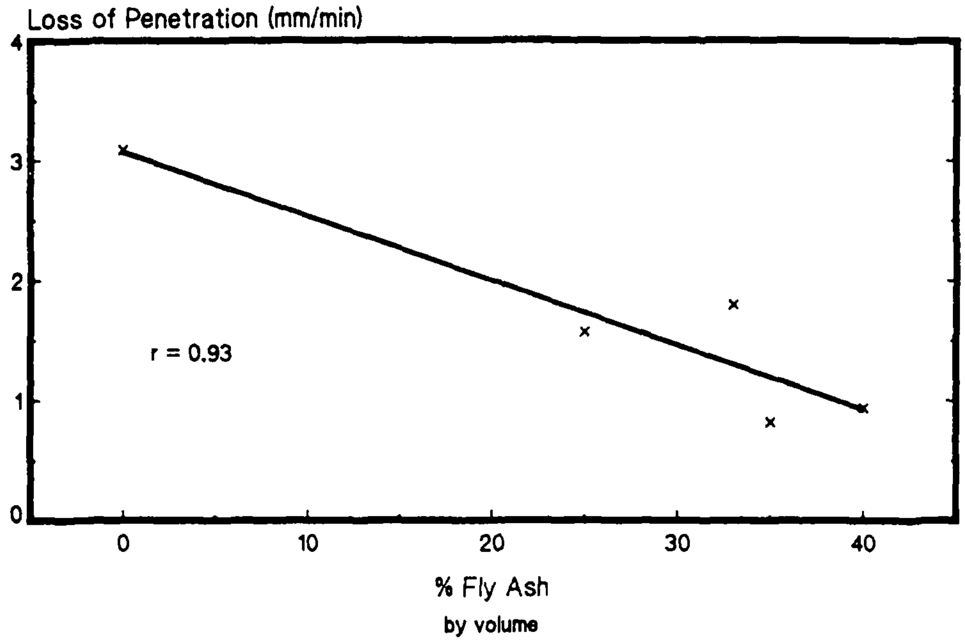

Figure 7. Effect of percent replacement of portland cement (by volume) with fly ash on rate of loss of penetration in ASTM C 359 tests. Each point represents a single test result.

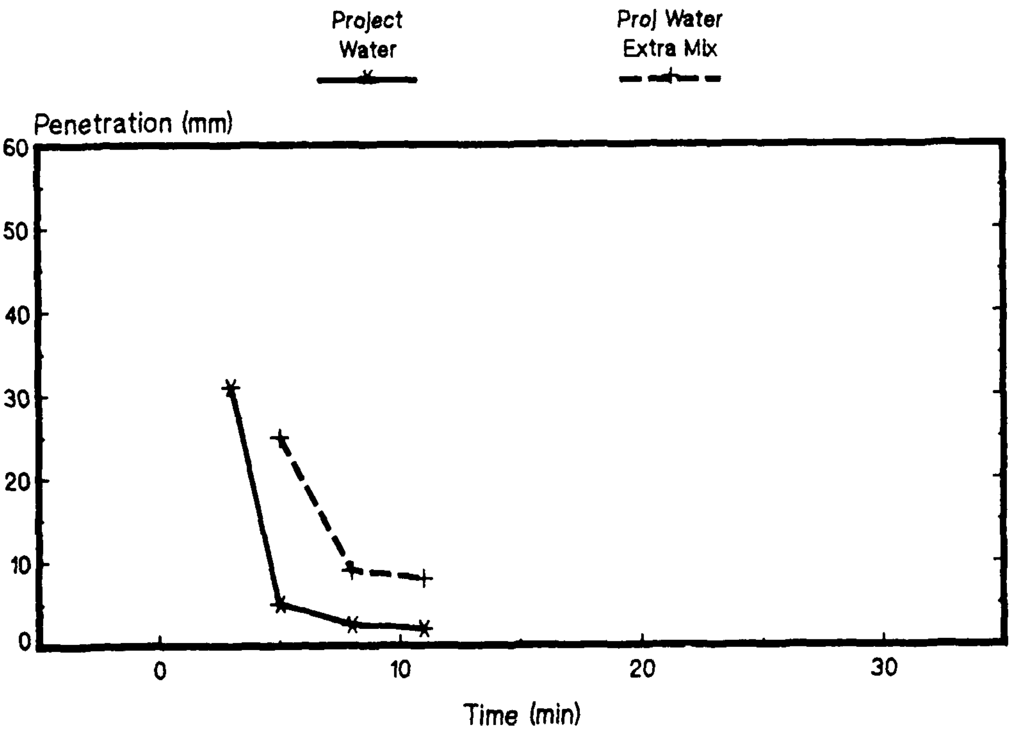

Figure 8. Effect of 1 min of extra mixing on penetration vs. time behavior of neat cement mortars. Each curve represents a single test.

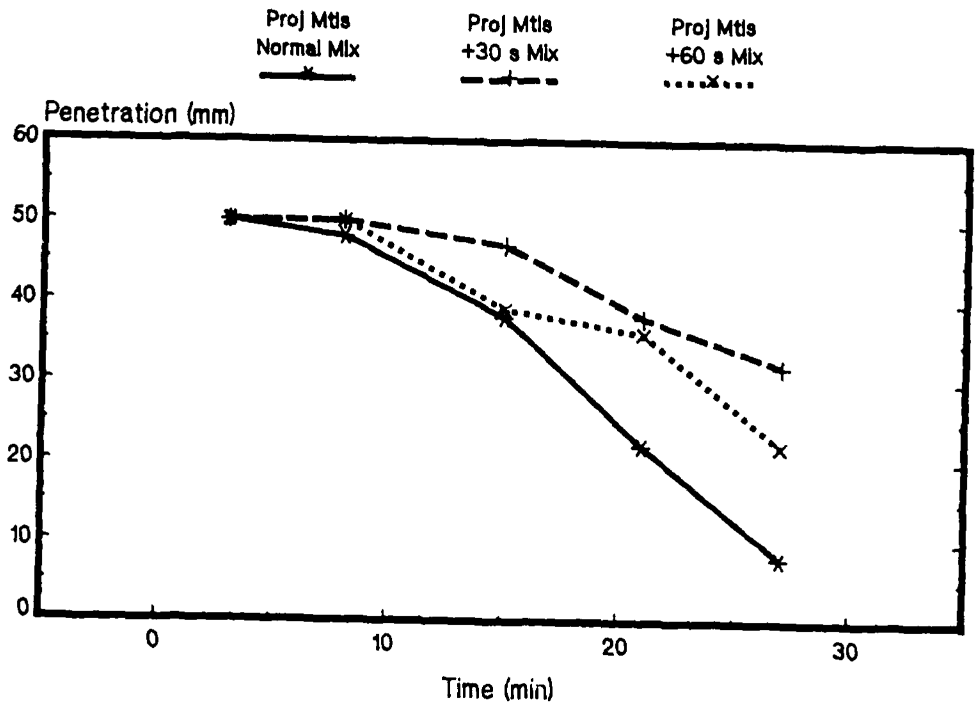

Figure 9. Effect of 30 sec and 1 min of premixing of dry materials on penetration vs. time behavior of mortars containing fly ash. Each curve represents a single test.

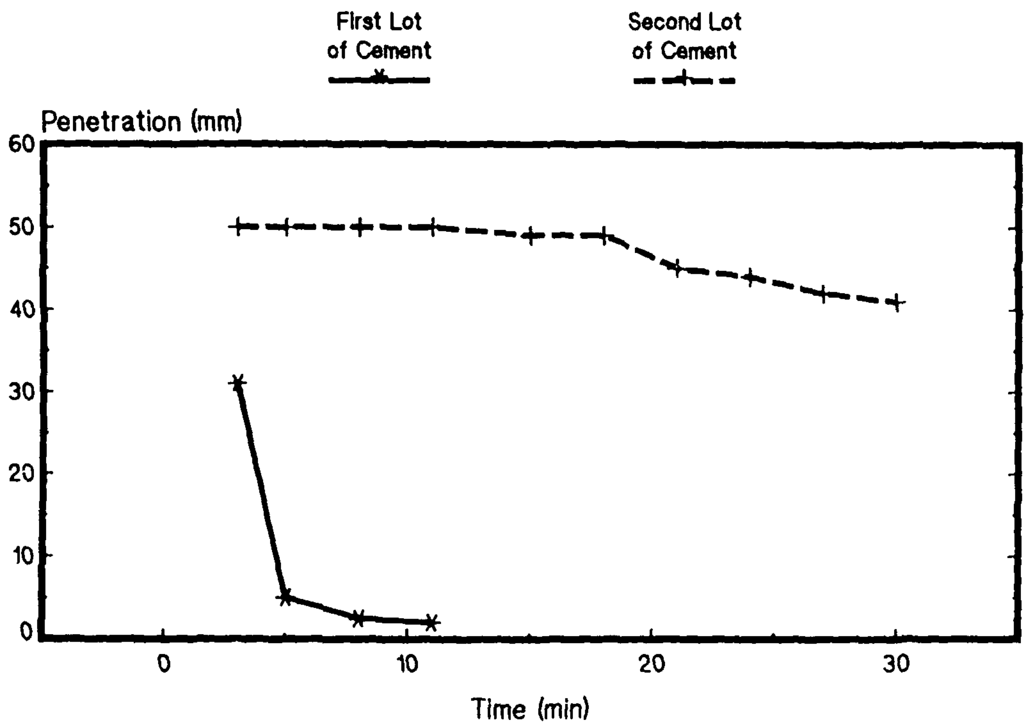

Figure 10. Comparison of penetration vs. time behavior of first lot of portland cement with second lot of portland cement.

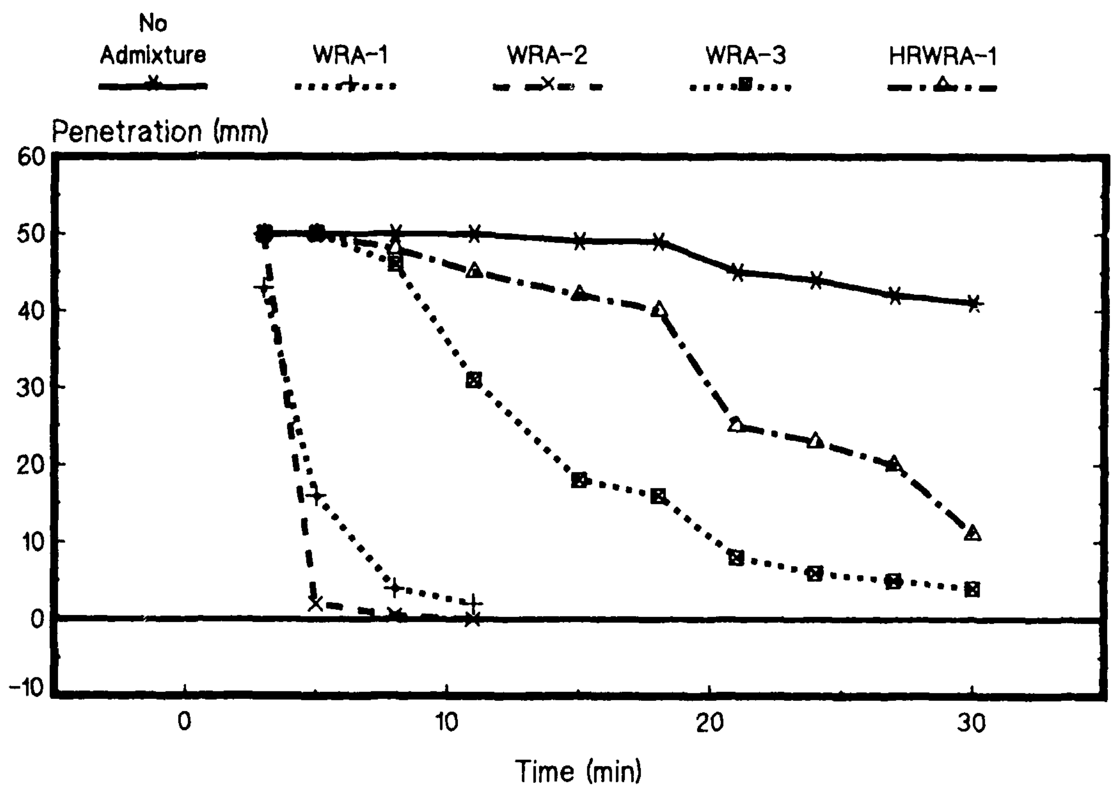

Figure 11. Effect of four water reducing admixtures on penetration vs. time behavior of portland cement.

Appendix A. ASTM C 359 (modified) Test Data, Penetration (mm) vs Time (min).

Part 1

PROJECT CEMENT
(LMK 136-88)

		Proj Fly Ash (LMK 135C-88)				Alt Fly Ash (WES 14F-88)			
Time from		Proj Water		DI Water		Proj Water		DI Water	
Start Mix	Repl.	1	2	1	2	1	2	1	2
3 min		50	50	50	50	50	50	50	50
8		44	48	50	50	41	36	46	50
15		27	38	46	50	28	28	42	48
21		16	22	39	49	16	12	39	48
27		6	8	37	46	11	12	39	43
30		11	-	26	38	12	9	35	41
Remix		50	50	50	50	50	50	50	50

ALTERNATE CEMENT
(SWF 145-88)

		Proj Fly Ash (LMK 135C-88)				Alt Fly Ash (WES 14F-88)			
Time from		Proj Water		DI Water		Proj Water		DI Water	
Start Mix	Repl.	1	2	1	2	1	2	1	2
3 min		50	50	50	50	50	50	50	50
8		50	50	50	50	50	50	50	50
15		50	50	50	50	45	47	50	44
21		46	44	44	45	44	42	46	38
27		30	18	41	42	39	39	41	34
30		25	26	39	40	37	39	39	23
Remix		50	50	50	50	50	50	50	50

MISCELLANEOUS TEST CONDITIONS

Time from Start Mix	Proj Water Proj Cement No Fly Ash	DI Water Proj Cement No Fly Ash	Proj Mix Decanted Hydr. Fe	Proj Mix +45 sec Mixing	Proj Mix +30 sec Premix	Proj Mix +60 sec Premix
3 min	31	29	23	-	50	50
5	5	10	2	25	-	-
8	2.5	8	1	9	50	50
11	2	6	1	8	-	-
Remix	34	41	36	36	no remix	
15					47	39
21					38	36
27					32	22
30					38	27
Remix					50	50

Part 2

Time	Control[1]	WRA-1[2]	WRA-2[3]	WRA-3[4]	HRWRA-1[5]
	Penetration (mm)				
3 min	50	35	50	50	50
5	50	26	2	50	50
8	50	8	5	46	48
11	50	5	0	31	45
15	49	2		18	42
18	49			16	40
21	45			8	25
24	44			6	23
27	42			5	20
30	41			4	11
Remix	50	50		50	50

1 mean of three determinations using cement LMK 14-89.
2 mean of two determinations using cement LMK 14-89 and LMK 26-89. Job admixture.
3 single determinations using cement LMK 14-89.
4 mean of two determinations using cement LMK 19-89 and LMK 26-89.
5 single determination using cement LMK 26-89. High range water reducer.

Appendix B. Statistical Analysis, 2x2x2 Completely Randomized Design.

Analysis of Variance Procedure
Class Level Information

Class	Levels	Values
CEMENT	2	ideal txi
FA	2	gh tr
WATER	2	di job

Number of observations in data set = 16

Analysis of Variance Procedure

Dependent Variable: RATE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	3.89229375	0.55604196	16.66	0.0003
Error	8	0.26695000	0.03336875		
Corrected Total	15	4.15924375			

R-Square	C.V.	Root MSE	RATE Mean
0.935818	21.19462	0.182671	0.86187500

Analysis of Variance Procedure

Dependent Variable: RATE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
CEMENT	1	0.70980625	0.70980625	21.27	0.0017
FA	1	0.13140625	0.13140625	3.94	0.0825
WATER	1	1.82925625	1.82925625	54.82	0.0001
CEMENT*FA	1	0.00765625	0.00765625	0.23	0.6448
CEMENT*WATER	1	0.87890625	0.87890625	26.34	0.0009
FA*WATER	1	0.22800625	0.22800625	6.83	0.0309
CEMENT*FA*WATER	1	0.10725625	0.10725625	3.21	0.1108

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: RATE

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 0.033369

Number of Means 2
Critical Range 0.210

Means with the same letter are not significantly different.

Analysis of Variance Procedure

Duncan Grouping	Mean	N	CEMENT
A	1.0725	8	ideal
B	0.6512	8	txi

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: RATE

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 0.033369

Number of Means 2
Critical Range 0.210

Means with the same letter are not significantly different.

Analysis of Variance Procedure

Duncan Grouping	Mean	N	FA
A	0.9525	8	gh
A			
A	0.7712	8	tr

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: RATE

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 0.033369

Number of Means	2
Critical Range	0.210

Means with the same letter are not significantly different.

Analysis of Variance Procedure

Duncan Grouping	Mean	N	WATER
A	1.2000	8	job
B	0.5238	8	di